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Forest Floor Fuel Loads, Depths, and Bulk Densities in Four Interior Alaskan Cover Types

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ABSTRACT

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Forest floor fuel loads, depths, and bulk densities are reported for four Interior Alaska cover types. Cover types included are upland black spruce, lowland black spruce, white spruce, and paper birch. Results indicate forest floor depths range from slightly over 2 inches to about 7 inches for all areas sampled. Loads range from 2.1 lb/ft^2 to 3.4 lb/ft^2 (10.25 kg/m^2 to 16.60 kg/m^2), while bulk densities ranged from 4.9 lb/ft^3 to 10.6 lb/ft^3 (78.50 kg/m^3 to 169.81 kg/m^3). Study results compare favorably with similar work in other locations.

KEYWORDS: fuels, fuel loads, fuel depths, fuel bulk densities, Alaska

The forest floor has an important influence on the hydrologic characteristics of a site. Amount of organic material, its depth, and bulk densitites are fundamental in describing forest soil characteristics. The forest floor is also a very important fuel component which influences ignition and subsequent fire behavior. The forest floor is generally defined as the accumulated organic matter above mineral soil. This matter consists of three layers: the L layer, consisting of unaltered organic matter; the F layer, consisting of partly decomposed matter; and the H layer, consisting of well decomposed matter.

Information regarding the forest floor is absolutely necessary in evaluating the effects of fire, either wildfire or prescribed fire. The intensity and duration of a fire is related to the fuels and fuel moisture, and the forest floor is an important component. The depth of material and the depth of burn can affect the amount of subsurface killing of plant parts; so we must know more about this portion of the system.

Since the development of fire behavior models (Rothermel 1972) and their subsequent sophistication, fire researchers and fire managers alike have become more interested in the characteristics of forest vegetation. Improvements in and concern for forest fuel inventories, changes in fire management policies, fire use, and computerization have all contributed to the need for more and better information regarding forest and range biomass as a fuel. This note reports some of the information needed by those utilizing fuel data with today's technology to better predict possible outcomes of various management strategies and the impact of fire.

METHODS

Four sampling sites were selected that represent cover types commonly visited by fire in Interior Alaska. The characteristics of each sample site are detailed in table 1 (for SI unit table, see appendix table 7). These sites are all within the Fairbanks vicinity. The specific site location is the Bonanza Creek Experimental Forest, latitude 64°45' N. and longitude 148°15' W.

The dominant representative ground fuel (moss or leaf litter) in each general cover type was considered for sampling. An effort was made to take as uniform and representative a fuel sample as possible. The reader is cautioned to remember that this study was a localized sample and may not represent Interior Alaska as a

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Table 1.—Sample stand characteristics

Dominant overstory species	Elevation	Topography	Aspect	Slope	Soils	Permafrost	Density	Dominant overstory species			Mean
								Basal area	Age	Height	d.b.h.
	Feet			*Percent*			*Stems/acre*	*Ft²/acre*	*Years*	*Feet*	*Inches*
Birch (*Betula papyrifera* Marsh.)	1,550	Slope	S	10-20	Ester Silt loam	Intermittent	303	10	110-130	55	8.0
Upland black spruce (*Picea mariana Mill.)*	1,155	Spur ridge	S	0-10	Ester Silt loam	Intermittent	2,000	149	101	33	3.7
Lowland black spruce (*Picea mariana* Mill.)	550	Flat		0	Alluvial Tanana Silt loam	Present	11,067	82	51	9	1.05 d.g.h.[1]
White spruce *(Picea glauca* [Moench] Voss*)*	575	Rolling	S	0-10	Ester Silt loam	Intermittent	425	118	62	67	6.8

[1] d.g.h. = diameter ground height or basal diameter.

whole. Within-site and between-site differences indicate that variability is common and rather larger in some instances. Samples were dried to a constant weight in order of collection at 217° F (103° C).

Samples 1 ft^2 (0.09 m^2) were taken down to mineral soil. In areas with mosses as the predominant vegetation, as in the spruce stand, samples were stratified as follows:

1. Green moss, dead moss, or the litter layer (L) and the fermentation layer (F).
2. Humus layer (H) down to, but not including, the mineral soil.

At the time of sampling, the depth of each layer was recorded to the nearest one-half inch (1.25 cm). Small herbs and shrubs growing within the sample were included, the top material being combined with the L and F layers. Large material, such as limbs, was removed. In the birch type, the litter (L) and humus (H) layers were combined. These layers were not separated because of the difficulty of doing so throughout the season. The F layer was often indistinct and the L layer was sometimes very shallow. Three 1-ft^2 (0.09-m^2) samples were taken at each site, including all material down to, but not including, mineral soil at each sampling time. A total of 114-120 samples were taken over a period of 4 summers. Sample numbers differed between cover types. The sample sites were visited from 10-14 times each summer for the period of the study.

RESULTS

Sample statistics for forest floor depths, loads, and bulk densities are summarized in table 2 (for SI unit table, see appendix table 8) by forest cover type and forest floor layer.

Total forest floor depth (litter plus humus layers) averaged about 4 inches (10 cm) in the birch and white spruce stands and was slightly over 6.5 inches (16.5 cm) in the upland and lowland black spruce stands. Standard deviations of litter and humus depths ranged from 30 to 40 percent of the means while standard errors were quite low, 3 to 4 percent. Within each cover type, the litter and humus layers appeared to have approximately equal depths. The fuel loads of the humus layers, on the other hand, were from two to four times greater than those of the litter layers within each cover type. Litter loads ranged from 0.51 to 0.75 lb/ft^2 (2.49 to 3.66 kg/m^2), and humus loads ranged from 1.62 to 2.34 lb/ft^2 (7.91 to 11.42 kg/m^2). The standard deviations for loads ranged from 39 to 80 percent, exhibiting greater variability than forest floor depths even though the standard errors remained quite low (4 to 7 percent of the means).

The difference between litter and humus layer loads is manifested in the bulk densities of the two layers. Humus bulk densities were two to three times greater than those of the corresponding litter layer. Litter bulk densities averaged 3.2 lb/ft^3 (51.3 kg/m^3) for all three spruce stands while humus bulk densities ranged from 6.9 to 9.1 lb/ft^3 (111 to 146 kg/m^3). Bulk density standard deviations ranged from 38 to 108 percent of the mean, showing still greater variability than either forest floor depth or load. Standard errors of the mean remained low at 4 to 10 percent.

The results in table 2 suggest the possibility that forest floor depth, load, and bulk density did not vary significantly between the upland black spruce, lowland black spruce, and white spruce stands for the litter or humus layers. An analysis of variance was conducted to test the hypothesis that forest floor depth, load, and bulk density were the same for the three cover types. Significant differences ($p < 0.05$) between cover types were found only in the litter and humus layer bulk densities (table 3). A Scheffé multiple mean comparison test showed litter bulk densities to be alike for all three spruce types at $p < 0.05$. The same test differentiated two cover type groups for humus layer bulk density; lowland black spruce, and upland black spruce—white spruce.

Table 2.—Litter and humas layer depths, loads, and bulk densities for four Alaskan forest cover types

Forest cover type	Layer[1]	Depth			Load			Bulk density			Sample size
		Mean	Standard deviation	Standard error	Mean	Standard deviation	Standard error	Mean	Standard deviation	Standard error	
		Inches			*Lb/ft^2*			*Lb/ft^3*			
Birch	L + H	4.04	1.46	0.13	3.41	1.55	0.14	10.60	4.78	0.44	119
Upland black spruce	L	2.79	1.08	.10	.64	.28	.03	3.09	1.58	.14	120
	H	3.78	1.67	.15	2.34	1.88	.17	8.91	9.66	.88	120
	L + H	6.75	2.31	.21	2.98	1.91	.17	6.00	4.44	.41	120
Lowland black spruce	L	2.88	1.00	.09	.75	.29	.03	3.24	1.24	.16	114
	H	3.62	1.82	.17	1.76	.86	.08	6.91	4.45	.42	114
	L + H	6.50	2.39	.22	2.49	.91	.09	4.94	2.15	.20	114
White spruce	L	2.15	.76	.07	.51	.21	.02	3.27	1.83	.17	117
	H	2.29	.90	.08	1.62	.88	.08	9.14	4.54	.42	116
	L + H	4.43	1.29	.12	2.12	.97	.09	6.12	3.06	.28	117

[1] L = litter layer, H = humas layer, L + H = litter and humus layers.

Table 3. — Analysis of variance statistics of forest floor depths, loads, and bulk densities by forest cover type and forest floor layer

Variable	Litter layer[1]		Humus layer[1]		Litter and humus[2]	
	F ratio	(d.f.)	F ratio	(d.f.)	F ratio	(d.f.)
Depth	[3]20.5	(2,348)	[3]34.3	(2,348)	[3]57.1	(3,466)
Load	[3]23.4	(2,354)	[3]10.3	(2,352)	[3]19.1	(3,466)
Bulk density	.47	(2,348)	3.80	(2,346)	[3]52.1	(3,466)

[1] Analysis of variance between upland black spruce, lowland black spruce, and white spruce.

[2] Analysis of variance between birch, upland black spruce, lowland black spruce, and white spruce.

[3] $p < 0.05$

The possibility of using forest floor depth to predict layer loads and bulk densities was investigated. The capability deriving litter and humus load and bulk density from depth measurements would greatly expedite fuel sampling in the four cover types.

The correlation coefficients (Pearson's simple r) of litter, humus, and litter-humus depths with their associated loads and bulk densities are presented in table 4. The load and bulk density values were converted using natural logarithm transformations to more closely approximate a normal distribution.

Table 4. — Pearson correlation coefficients of forest floor depth with load and bulk density by forest cover type and forest floor layer

Forest cover type	Layer[1]	Forest floor depth correlation coefficient with:		
		ln (load)	ln (bulk density)	n
Birch	L + H	[2]0.497	[2]−0.243	119
Upland black spruce	L	.279	[2]− .492	120
	H	[2] .313	[2]− .522	120
	L + H	.190	[2]− .526	120
Lowland black spruce	L	[2] .471	[2]− .424	114
	H	[2] .362	[2]− .503	113
	L + H	[2] .339	[2]− .452	114
White spruce	L	.047	[2]− .692	117
	H	[2] .351	[2]− .403	116
	L + H	.157	[2]− .458	117

[1] L = litter layer, H = humus layer, L + H = litter and humus layers.

[2] $p < 0.01$.

The correlation between depth and load was modest, but statistically significant, for all cover types and layers except the white spruce litter layer and the white and lowland black spruce litter-humus layers. The correlation between depth and bulk density was significant ($p < 0.05$), but moderate, for all cover types and layers. The depth correlations with bulk densities tended to be better than those for depth with load. This is not unexpected since depth is one of the factors determining bulk density.

Finally, linear regressions were determined between the litter and humus layer depths and their associated natural logarithm transforms of load and bulk density. The forms of the equations are:

$\ln(Y) = \alpha + \beta X + e$ where
$Y =$ dependent variable
$\alpha =$ intercept
$\beta =$ slope
$X =$ layer depth (inches)
$e =$ regression error.

For loads, Y and α have units of lb/ft^2, and for bulk densities, Y and α have units of lb/ft^3.

Again, the linear relationships between depths and loads and between depths and bulk densities are significant but too weak to be useful for prediction purposes (table 5). Only the three depth-load regressions for spruce litter-humus layers have insignificant slopes ($p < 0.05$). In only one instance does the simple linear regression account for more than 30 percent of the variance in the data.

Table 5. — Regression statistics for forest floor load and bulk density as a function of depth by forest cover type and forest floor layer

Forest cover type	Layer[1]	*ln* (load) = $\alpha + \beta$ (depth)					*ln* (bulk density) = $\alpha + \beta$ (depth)				
		Intercept	Slope	r^2	SEE	n	Intercept	Slope	r^2	SEE	n
Birch	L + H	[2]-0.363	[2]0.183	[2]0.25	0.468	119	[2]2.657	-0.076	[2]0.06	0.443	119
Upland black spruce	L	- .839	[2] .112	[2] .08	.419	120	[2]1.641	- .225	[2] .25	.427	119
	H	[2] .344	[2] .096	[2] .10	.490	120	[2]2.653	- .181	[2] .27	.497	120
	L + H	[2] .819	.027	.01	.407	114	[2]2.544	- .138	[2] .27	.403	114
Lowland black spruce	L	[2]- .880	[2] .176	.22	.331	114	[2]1.551	- .153	[2] .18	.328	114
	H	.063	[2] .104	.13	.487	113	[2]2.351	- .163	[2] .25	.510	113
	L + H	[2] .429	.064	[2] .07	.379	107	[2]2.165	- .104	[2] .17	.383	107
White spruce	L	[2]- .695	-.024	.00	.393	117	[2]2.085	- .485	[2] .48	.388	116
	H	- .096	[2] .198	[2] .12	.478	116	[2]2.616	- .230	[2] .16	.472	116
	L + H	[2] .430	.052	.03	.425	117	[2]2.506	- .178	[2] .26	.389	116

[1] L = litter layer. H = humus layer, L + H = litter and humus layers.

[2] $p < 0.01$.

SUMMARY AND CONCLUSIONS

Individual litter and humus layer depths are similar in the four Alaskan cover types studied. Mean total (litter plus humus) depths averaged about 4 inches (10 cm) in birch and white spruce stands, and approximately 6 inches (15 cm) in both upland and lowland black spruce areas. The natural variability of litter and humus layer depths, as expressed by the coefficient of variability (percent), ranged from 31 to 43 for the seven cover type-layer combinations.

The humus layer contained from two to four times as much biomass as did the litter layer. Litter layer loads ranged from 0.51 to 0.75 lb/ft^2 (2.49 to 3.66 kg/m^2) in the white spruce and two black spruce stands. In the same areas, humus layer loads ranged from 1.62 to 2.34 lb/ft^2 (7.91 to 11.42 kg/m^2). The natural within-stand variability of litter and humus loads for the three stands ranged from 52 to 143 percent, while the sample error (standard error) ranged from 4 to 7 percent of the mean.

The humus layer generally has a bulk density two to three times greater than the litter layer. Humus layer bulk densities were on the order of 7 to 10 lb/ft^3 (112 to 160 kg/m^3), while litter layer bulk densities averaged about 3 lb/ft^3 (48 kg/m^3). Within-stand variability ranged from 26 to 58 percent while standard erros were from 4 to 9 percent.

Weak, but generally highly significant relationships, as expressed by Pearson's coefficient of correlation (r), were found between litter or humus layer depths and their associated loads and bulk densities. Linear regressions of litter or humus layer depth (independent variable) with loads and bulk densities (dependent variables) were performed. Again, regressions were generally significant, but accounted for less than 30 percent of the variability in the data. One possible explanation for the weak correlations is that with depth measurements of one-half inch (1.27 cm) increments were too coarse considering the total depth encountered. A more precise measurement could have improved the resulting analysis. Also, extreme variation between samples was encountered which can also help explain part of the problem.

The bulk density data developed in this study compare relatively well with similar data from other areas. The birch data, however, are considerably higher for this study than the data reported by Troth and others (1976) (table 6). Considering the standard deviation, it is, however, within the general range. Comparison with black spruce data shows very close agreement with other values reported in Canada, Michigan, and Alaska. The Canadian black spruce bulk density values range from 2.68 lb/ft^3 to 15.61 lb/ft^3 (0.043 g/cm^3 to 0.25 g/cm^3) whereas the data from this study range from 3.16 lb/ft^3 to 10.25 lb/ft^3 (0.05 g/cm^3 to 0.16 g/cm^3). These data are well within the range of bulk densities reported elsewhere for black spruce. The other bulk density data for species such as white spruce-balsam poplar, ponderosa pine, red pine, jack pine, spruce-fir, and lodgepole pine all appear to have forest floor bulk densities in the same general range.

Practical application of these data will be made in defining forest floor characteristics and water relations, as well as moisture response characteristics. Because of the forest floor's importance as a source of fuel for either wildfires or prescribed fires, these data will eventually be used in combination with other fuel properties, such as moisture content, to predict fire behavior and resultant fire effects. Increased understanding of the forest system and its properties as a whole will improve our ability to make better management decisions and application.

Table 6. — A comparison of mean bulk densities from several locations and sources

Source	Layer	Species	Location	Mean bulk density	
				Lb/ft³	*g/cm³*
Mader (1953)	F,H	White spruce	Ontario		
		Balsam poplar	Ontario	9.99	0.16
	F,H	Black spruce, spruce	Michigan	4.99	.08
	F,H	Black spruce	Ontario	15.61	.25
Brown (1966)	F,H	Red pine	Minnesota	4.32	.069
	F,H	Jack pine	Michigan	6.1	.098
Ffolliott and others (1968)	F	Ponderosa pine	Arizona	1.8	.029
Mader and Lull (1968)	F	White pine	Massachusetts	4.5	.072
	H	White pine	Massachusetts	9.0	.144
Brown (1970)	F,H	Ponderosa pine	Montana	4.74	.076
Kiil (1970)	F,H	Spruce-fir	Alberta	3.75	.06
Golding and Stanton (1972)		Spruce-fir	Alberta	6.24	.10
		Lodgepole pine	Alberta	8.74	.14
Troth and others (1976)	L,F,H	Black aspen	Alaska	3.64	.058
	L,F,H	Black spruce	Alaska	3.25	.052
Viereck and Dyrness (1979)	L,F,H	Black spruce	Alaska	2.68	.043
	L,F,H	Black spruce	Alaska	4.81	.077
	L,F,H	Black spruce	Alaska	8.49	.136

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APPENDIX TABLES

Table 7. — Sample stand characteristics

Dominant overstory species	Elevation	Topography	Aspect	Slope	Soils	Permafrost	Density	Dominant overstory species			Mean
								Basal area	Age	Height	d.b.h.
	Meters			*Percent*			*Stems/ha*	*m²/ha*	*Years*	*Meters*	*cm*
Birch (*Betula papyrifera* Marsh.)	472.75	Slope	S	10-20	Ester Silt loam	Intermittent	748	2.29	110-130	16.78	20.32
Upland black spruce (*Picea mariana* Mill.)	352.28	Spur ridge	S	0-10	Ester Silt loam	Intermittent	4,942	34.21	101	10.07	9.40
Lowland black spruce (*Picea mariana* Mill.)	167.75	Flat		0	Aluvial Tanana Silt loam	Present	27,346	18.83	51	2.74	2.67 d.g.h.[1]
White spruce	175.38	Rolling	S	0-10	Ester	Intermittent	1,050	27.09	62	20.43	17.27

[1] d.g.h. = diameter ground height or basal diameter.

Table 8. — Litter and humus layer depths, loads, and bulk densities for four Alaskan forest cover types

Forest cover type	Layer[1]	Depth			Load			Bulk density			Sample size
		Mean	Standard deviation	Standard error	Mean	Standard deviation	Standard error	Mean	Standard deviation	Standard error	
		Centimeters			*kg/m²*			*kg/m³*			
Birch	L + H	10.3	3.71	0.33	16.65	7.57	0.68	169.8	76.6	7.0	119
Upland black spruce	L	7.09	2.74	.25	3.12	1.37	.15	49.5	25.3	2.2	120
	H	9.60	4.24	.38	11.42	9.18	.83	142.7	154.8	14.1	120
	L + H	17.15	5.87	.53	14.55	9.33	.83	96.1	71.1	6.6	120
Lowland black spruce	L	7.32	2.54	.23	3.66	1.42	.15	51.9	19.9	2.6	114
	H	9.19	4.62	.43	8.59	4.20	.39	110.7	71.3	6.7	114
	L + H	16.51	6.07	.56	12.16	4.44	.44	79.1	34.4	3.2	114
White spruce	L	5.46	1.93	.18	2.49	1.03	.10	52.4	29.3	2.7	117
	H	5.82	2.29	.20	7.91	4.30	.39	146.4	72.7	6.7	116
	L + H	11.25	3.28	.30	10.35	4.74	.44	98.0	49.0	4.5	117

[1] L = litter layer, H = humus layer, L + H † litter and humus layers.

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